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A Study of Jets From Unsintered-Powder Metal Lined Nonprecision Small-Caliber Shaped Charges

by William Walters, Philip Peregino, Richard Summers, and David Leidel

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A Study of Jets From Unsintered-Powder Metal Lined Nonprecision Small-Caliber Shaped Charges

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Abstract

A study was conducted to characterize and investigate the performance of shaped charge devices fabricated with powder metal liners. The investigation involved free-flight flash radiography characterization of the jet to obtain the penetrator characteristics and the penetration and hole size into rolled homogenous armor (RHA) plate at several standoff distances.

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1. Introduction

The U.S. Army Research Laboratory (ARL) obtained a sample of powder metal-lined nonprecision shaped charges from Halliburton Energy Services located in Alvarado, TX. These shaped charges, designated as the 4 5/8-in PM OMNI, are designed and manufactured for use as oil-well or gas-well perforators. The agreement with Halliburton Energy Services involved a complete study of these rounds. They were being investigated as a potential shaped charge to be used in the controlled detonation, containment, and decontamination of chemical munitions by the U.S. Army Garrison Directorate of Safety, Health, and the Environment (DSHE) at Aberdeen Proving Ground (APG). ARL is interested in charges of this type due to their design for optimum performance at short standoff, the short charge length and head height, the fact that the charges are inexpensive, and their potential application as precursor charges against specialized targets. The authors also have an interest in modeling the penetration of a powder-metal jet. Thus, the penetration standoff data will provide experimental data to verify a penetration model. This study is the subject of this report.

2. Charge Description

The 4 5/8-in OMNI refers to the outer diameter of the gun used to contain charges of this type for oil-well completions. The shaped charge is loaded in a pressure-sealed hollow steel container and fired downhole to establish a path of mass transport between a cased-well bore and the reservoir. The complete details of the charge are proprietary to the Halliburton Energy Services, but, basically, the liner was conical with an interior-included angle of 44°. The liner had an outer diameter of 1.37 in (3.48 cm). The outer diameter of the explosive charge was 1.51 in (3.84 cm); the outer diameter of the body was 1.86 in (4.72 cm); and the maximum overall diameter was 2.0 in (5.08 cm). The overall length of the charge was 1.72 in (4.37 cm). The liner had a wall thickness of 0.048 in (0.122 cm) at the apex and 0.064 in (0.1626 cm) at the base. The liners were fabricated from powder and were 43% copper by weight, 45% tungsten by weight, 11% tin by weight, and 1% graphite by weight. The liner was pressed to a density of

9.70 g/cm^3. The charge had a machined steel case. The explosive charge was 23 g of RDX pressed to a minimum density of 1.65 g/cm^3. The explosive contained approximately 0.5% paraffin for use as a binder and desensitizer. The charge was initiated by Ensign Bickford 80 gr/ft det cord with a detonation velocity of 7,500 to 7,850 m/s. The actual measured detonation velocity was 7,762 m/s. Figure 1 shows the steel-cased charge prior to the insertion of the det cord. The blue foam, which had a hollow core equal in diameter to the diameter of the charge, was used to set the standoff distance for the penetration vs. standoff distance shots. The det cord was taped on top of the charge, parallel to the target plate and standoff box. The length of det cord was 101.6 mm from the detonator to the RDX charge, with a 50.8 mm overlap past the charge. The det cord was initiated with an RP 80 exploding bridge wire (EBW) detonator. The known length and the detonation velocity of the det cord allowed the collapse timing to be accurately determined. All shots were fired vertically, with the jet propagation downward.

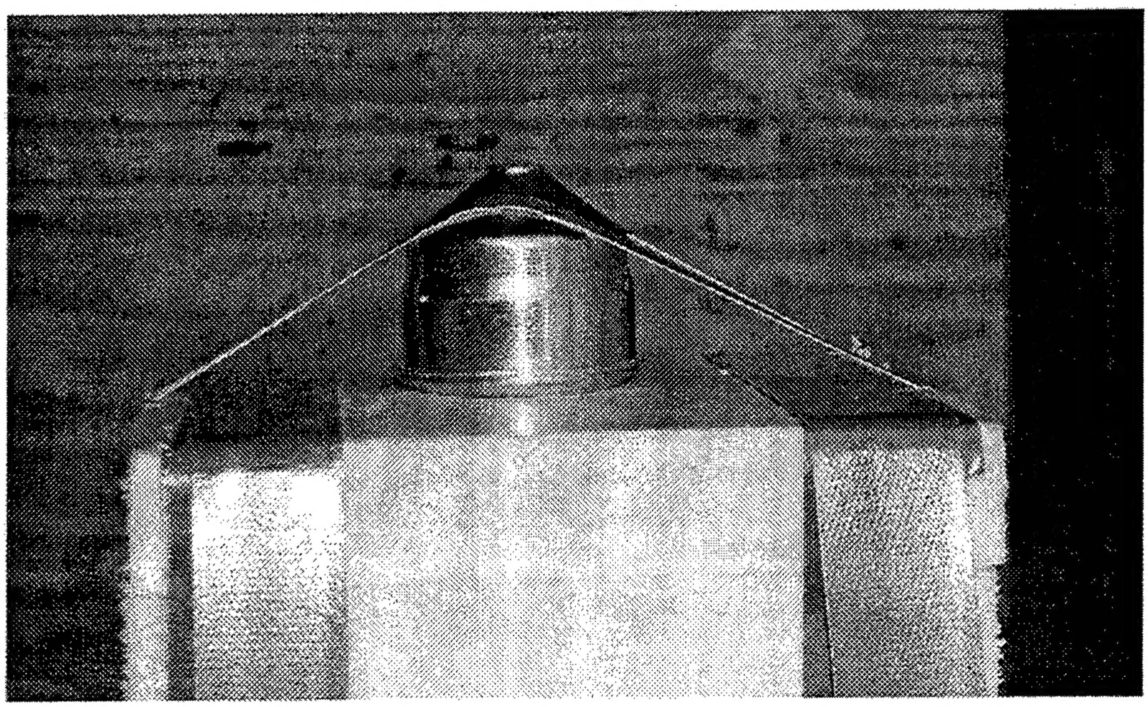

Figure 1. Photograph of the 4 5/8-in PM OMNI Charge.

3. Jet Characteristics

Figure 2 shows the charge setup prior to the flash radiography test to show the collapse of the liner, which is shown in Figure 3. Figure 3 does not contain sufficient resolution to measure the liner collapse angle but indicates that the liner appears to collapse (at least in a global sense) as a conventional (solid metal) liner. Jet characteristics were obtained for the free flight of the jet in air using the 300-kV flash x-ray system in the vertical test firing facility (described by Boyce et al.[1]) at ARL's Experimental Research Facility 7A. The free-flight data were obtained from two tests, namely rounds 4814 and 4815. Figure 4 shows the jet from round 4814 at 101.2, 121.3, and 141.2 μs after firing of the detonator. The average tip velocity determined from the early time exposures, less than 145 μs, was 6.6 km/s. Jet radii were measured using the exposures (shown in Figure 5) obtained at 121.3 μs (from round 4814) and 121.5 μs (from round 4815) after initiation. The jet radius measured near the front and the middle of the jet was 1.0 mm to 1.5 mm, and the radius near the rear of the jet was 3.0 mm to 3.5 mm. The jet from round 4815 was severely bowed. By 121.5 μs after initiation of the detonation cord, the jet-tip region was ablating in air (Figure 5). The tip velocity measured between this time and an exposure 45 μs later was 6.3 km/s. This discrepancy between early- and later-time tip velocities may be due to the ablation of the jet tip or to poor film contrast in the tip region of the later exposure caused by the lower apparent density of the incoherent jet tip. Note that since the jet does not particulate as conventional (solid metal) jets usually do, no other measurements were taken. The nominal penetration into rolled homogeneous armor (RHA) was 9 mm at a standoff distance of 2,095 mm.

4. Penetration Results

Tests were conducted to obtain penetration and hole profile diameter into 6 in (152.4 mm) × 5.75 in (146 mm) RHA plate 2 in (50.8 mm) thick. Based on a rough

[1] Boyce, G. L., G. E. Blackburn, M. L. Lake, S. C. Shelley Jr., and F. R. Schall. "The Construction and Operation of a New Warhead Test Facility." ARL-TR-322, U.S. Army Research Laboratory, Aberdeen Proving Ground, MD, December 1993.

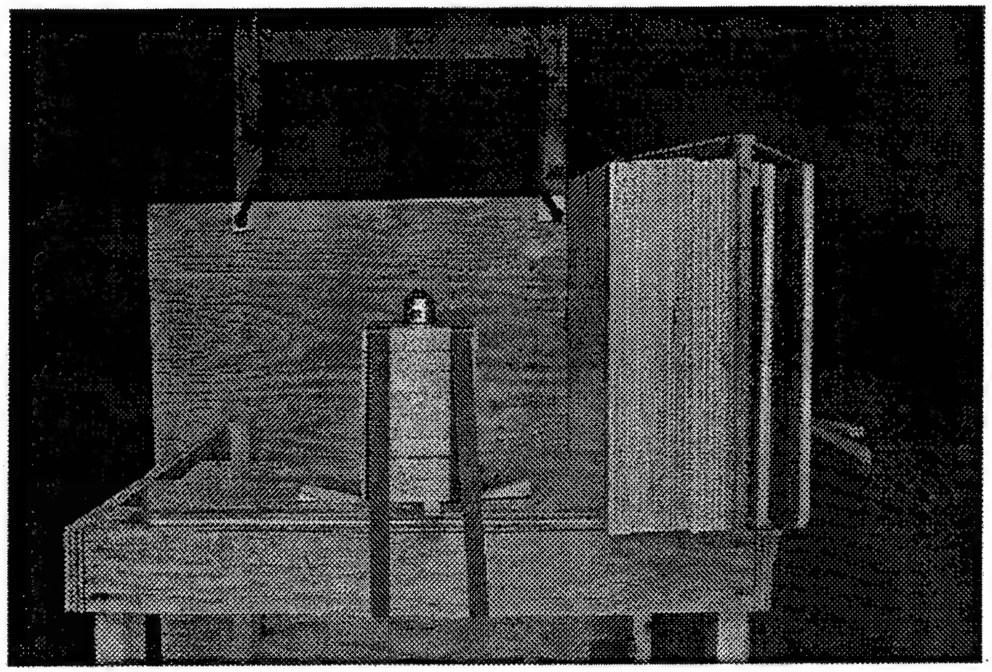

Figure 2. Test Setup.

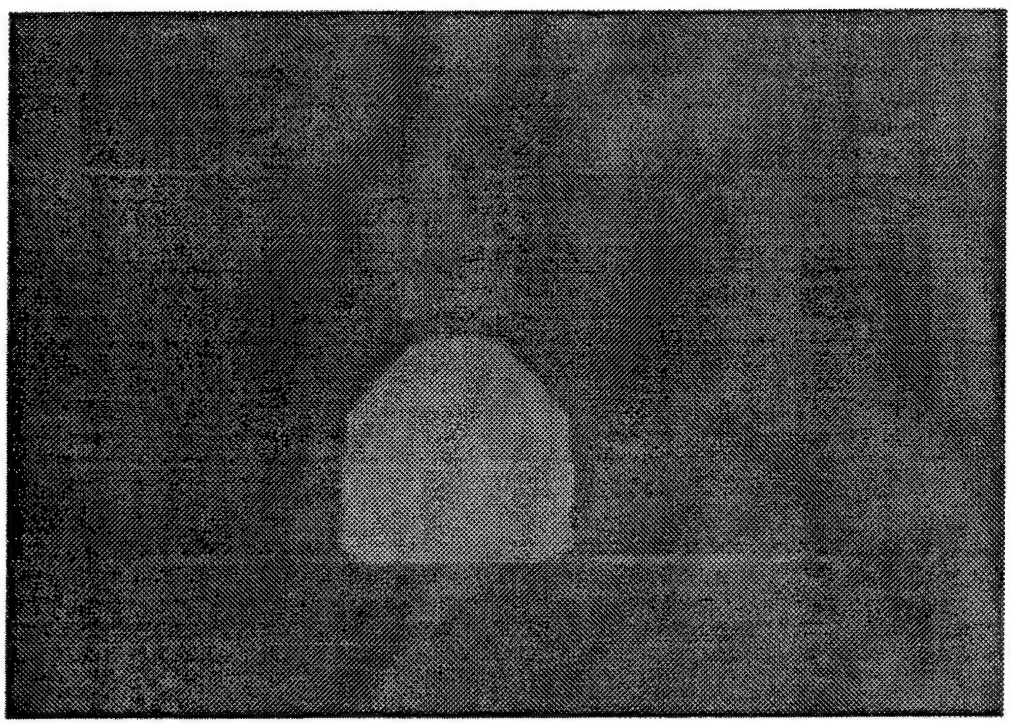

Figure 3. Early-Time Radiograph of Liner Collapse.

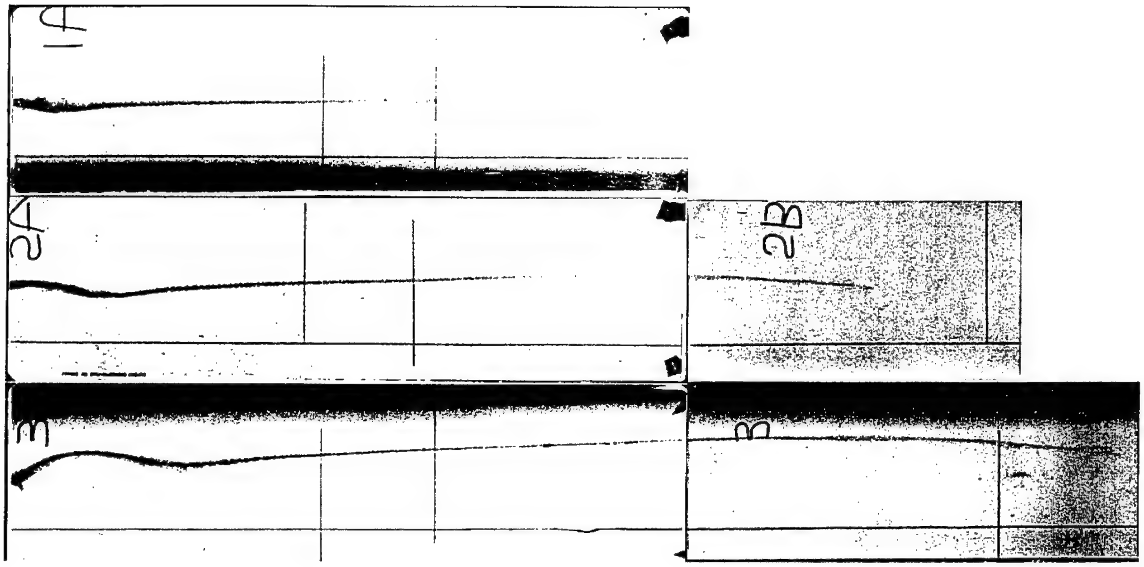

Figure 4. Flash Radiographs From the Jet-Free Flight, Round 4814.

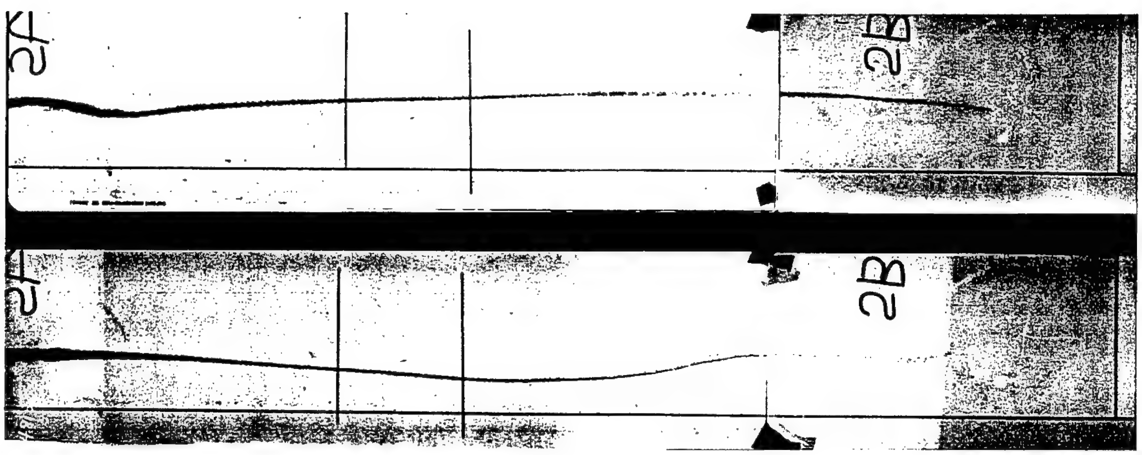

Figure 5. Flash Radiographs of the Jet Approximately 121 μs After Initiation for Rounds 4814 and 4815.

measurement, one charge diameter (CD) was defined to be 3.35 cm, and penetration standoff tests were conducted at 0.0, 1.0, 2.0, 3.0, 4.0, and 6.0 CD. Due to the scatter in the data, some shots were repeated, including tests at 2.5 and 3.5 CD. The peak penetration occurred at 3.0 CD. The penetration shots are recorded in Table 1, which gives penetration in millimeters and CD and standoff distances in centimeters and CD for penetration into 50.8-mm-RHA plate. These data are plotted in Figure 6. The hole profile data for each shot are given in the

Appendix. The hole profile data were based on rough measurements using calipers, and the plate was not sectioned to obtain exact hole sizes or final penetration. The hole size recorded is based on the maximum hole diameter in the x-y plane. Thus, the hole diameters are rough measurements and, as can be seen from the tabulations in the Appendix, jet material caused significant hole plugging. This would cause several of the plotted and tabulated penetration values to be low. The large amount of scatter in the data is discussed in the next section.

Table 1. Penetration Results

Standoff (cm)	Penetration (mm)	Standoff (CD)	Penetration (CD)	Plate Thickness (mm)
0.00	50.8	0.0	1.52	50.8
0.00	50.8	0.0	1.52	50.8
0.00	54.0	0.0	1.61	50.8
3.35	142.2	1.0	4.24	50.8
3.35	151.2	1.0	4.51	50.8
6.70	157.2	2.0	4.69	50.8
6.70	152.4	2.0	4.55	50.8
6.70	101.6	2.0	3.03	50.8
8.375	130.7	2.5	3.90	50.8
10.05	196.2	3.0	5.86	50.8
10.05	203.2	3.0	6.07	50.8
11.725	165.3	3.5	4.93	50.8
13.40	81.1	4.0	2.42	50.8
13.40	74.5	4.0	2.22	50.8
20.10	28.8	6.0	0.86	50.8
20.10	74.6	6.0	2.23	50.8
20.10	43.1	6.0	1.29	50.8
13.40	76.2	4.0	2.27	25.4
10.05	76.2	3.0	2.27	25.4
10.05	152.4	3.0	4.55	25.4
10.05	152.4	3.0	4.55	25.4 at 60°
10.05	118.0	3.0	3.52	25.4 at 60°

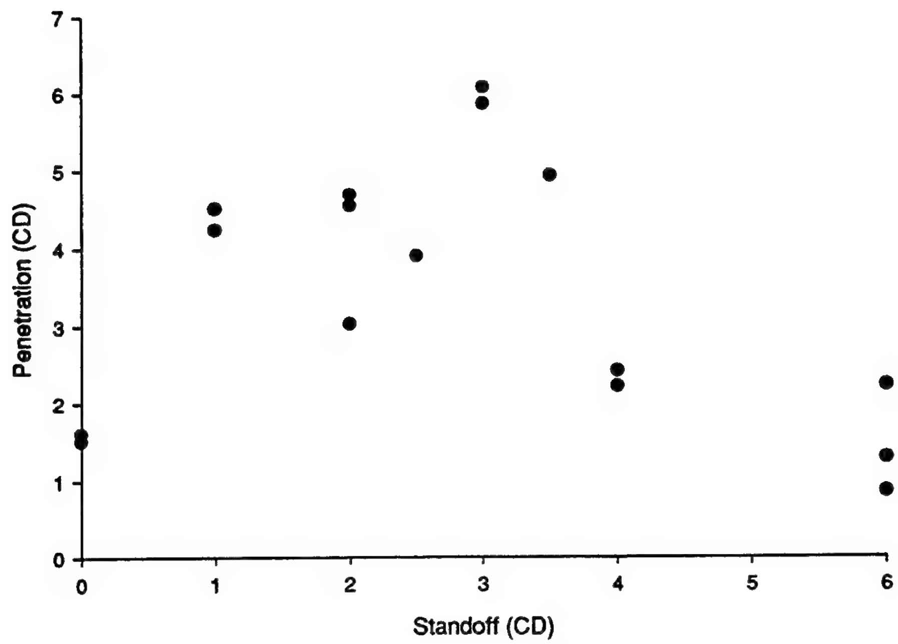

Figure 6. Penetration Into 2-in RHA Plate vs. Standoff Distance.

Next, the target RHA plate was changed to 6 × 6 in (152.4 × 152.4 mm) × 1 in (25.4 mm). One test was conducted at 4.0 CD and two tests at 3.0 CD. The 4.0-CD shot is in agreement with the results into the 2-in plate, and the two 3.0 CD shots show a low penetration value and a second value in agreement with the earlier results for the 2-in plate.

Finally, two tests were conducted at 3.0 CD into a 1-in plate at a 60° obliquity. These results, accounting for the fact that the penetration channels were often plugged, are in rough agreement with the results into the plate at 0° obliquity. These hole profiles (for all the shots into a 1-in plate) are also listed in the Appendix. For the 60° obliquity tests, copper was observed between the 1-in plates. Figure 7 adds the data points for the tests into the 1-in plate to those shots into the 2-in plate.

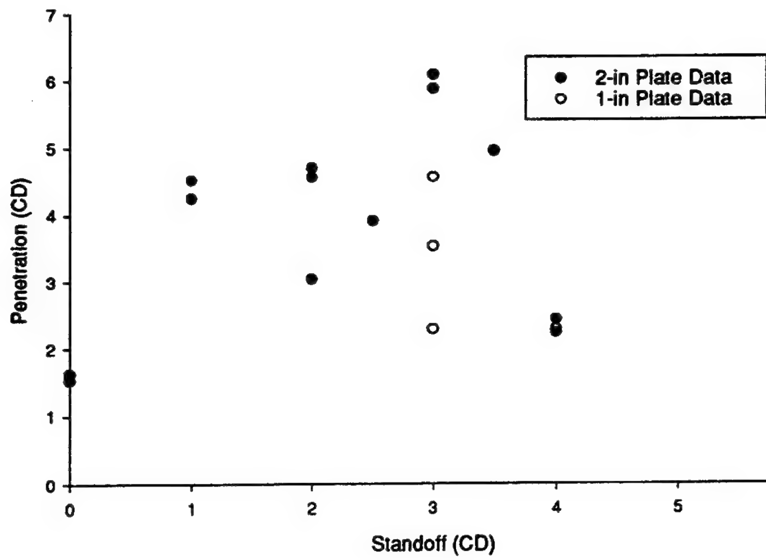

Figure 7. Penetration Into Both 1-in and 2-in RHA Plates vs. Standoff Distance.

5. Interpretation of Results and Conclusions

As previously mentioned, there is an excessive round-to-round variability in the penetration performance of the powder metallurgy liner shaped charges at standoff distances greater than 2 CD (6.7 cm). The performance is repeatable at short standoff distances (the standoffs where the jet was to be optimal) since the jet has not had time to form completely. At longer standoffs, the severe bowing and misalignment of the jet, as evident in Figure 4, would cause erratic jet performance. It is noted, however, that the shaped charge devices tested were not designed for RHA penetration, but for porous target penetration. Also, a peak penetration into RHA of 203.2 mm from this charge is impressive. The lack of repeatability is attributed to two factors. First of all, the liners tend to age or disintegrate over time due to humidity and other factors. (The liner actually begins to disintegrate.) The tests reported here were conducted over a period of several months, so the liners were exposed to local humidity for some time. Secondly, the wall thickness of the liner varied from charge to charge as did the concentricity between the liner

and the body. The test results reported herein supported Halliburton Energy Services program to acquire more precise assembly and parts presses and tooling to better control the uniformity of the liner and the alignment between the body and the liner.

Other test results seem to indicate that there was minimal difference in penetration between 25.4- and 50.8-mm-thick plates. Also, with due consideration given to the round-to-round variability, the effect of target plates at obliquity was minimal. These tests were conducted in order to establish whether or not the powder jet could be readily dispersed (like liquid jets) by oblique targets.

Finally, data were obtained that will aid in efforts to model the penetration of powdered jets into porous and/or nonporous targets.

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Appendix:

Hole Profile Data

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Penetration Into 50.8-mm RHA Blocks

Standoff 0.0 CD, 50.8-mm RHA blocks

Block No.	Entrance Hole (cm)	Exit Hole (cm)	Comments
1	1.5 × 1.5	0.92 × 0.38	slot
P = 50.8-mm			

Standoff 0.0 CD, 50.8-mm RHA blocks

Block No.	Entrance Hole (cm)	Exit Hole (cm)	Comments
1	1.215 × 1.215	0.95 × 0.42	slot
P = 50.8-mm			

Standoff 0.0 CD, 50.8-mm RHA blocks

Block No.	Entrance Hole (cm)	Exit Hole (cm)	Comments
1	1.03 × 1.18	0.72 × 0.32	slot
2	0.77 × 0.32		slot
P = 54.0 mm			

Standoff 1.0 CD, 50.8-mm RHA blocks

Block No.	Entrance Hole (cm)	Exit Hole (cm)	Comments
1	1.35 × 1.35	0.625 × 0.66	
2	0.62 × 0.54	0.42 × 0.42	
3	0.44 × 0.38	slight bulge	
P = 142.2 mm			

Standoff 1.0 CD, 50.8-mm RHA blocks

Block No.	Entrance Hole (cm)	Exit Hole (cm)	Comments
1	1.38 × 1.28	0.66 × 0.66	
2	0.55 × 0.55	0.28 × 0.36	
3	0.41 × 0.35	bulge	
P = 151.2 mm			

Standoff 2.0 CD, 50.8-mm RHA blocks

Block No.	Entrance Hole (cm)	Exit Hole (cm)	Comments
1	1.32 × 1.25	0.54 × 0.56	
2	0.61 × 0.57	1.0 × 1.04	hole plugged
3	1.0 × 1.0	0.43 × 0.48	hole plugged
4	splash		

P = 157.2 mm

Standoff 2.0 CD, 50.8-mm RHA blocks

Block No.	Entrance Hole (cm)	Exit Hole (cm)	Comments
1	1.28 × 1.11	0.62 × 0.62	hole plugged
2	0.64 × 0.63	0.57 × 0.61	hole plugged
3	0.50 × 0.49	0.13 × 0.25	hole plugged
4	splash		

P = 152.4 mm

Standoff 2.0 CD, 50.8-mm RHA blocks

Block No.	Entrance Hole (cm)	Exit Hole (cm)	Comments
1	1.42 × 1.05	0.66 × 0.78	
2	0.67 × 0.61	0.64 × 0.56	plugged exit
3	0.54 × 0.56		plugged hole

P = 101.6 mm + plug

Standoff 2.5 CD, 50.8-mm RHA blocks

Block No.	Entrance Hole (cm)	Exit Hole (cm)	Comments
1	0.93 × 1.46	0.52 × 0.57	
2	0.55 × 0.50	0.40 × 0.55	
3	0.46 × 0.54		

P = 130.7 mm

Standoff 3.0 CD, 50.8-mm RHA blocks

Block No.	Entrance Hole (cm)	Exit Hole (cm)	Comments
1	1.04 × 1.07	0.71 × 0.71	plugged
2	0.53 × 0.56	0.40 × 0.44	plugged
3	0.32 × 0.38	0.40 × 0.40	
4	0.42 × 0.38	slight bulge	

P = 196.2 mm

Standoff 3.0 CD, 50.8-mm RHA blocks

Block No.	Entrance Hole (cm)	Exit Hole (cm)	Comments
1	0.83 × 0.83	0.52 × 0.51	
2	0.58 × 0.54	0.42 × 0.38	plugged
3	0.41 × 0.42	0.31 × 0.31	plugged
4	0.43 × 0.43	0.38 × 0.47	plugged
5	0.45 × 0.55		hole plugged

P = 203.2 mm + plug

Standoff 3.5 CD, 50.8-mm RHA blocks

Block No.	Entrance Hole (cm)	Exit Hole (cm)	Comments
1	1.09 × 0.88	0.46 × 0.37	
2	0.45 × 0.51	0.41 × 0.41	
3	0.43 × 0.42	0.45 × 0.36	plugged
4	0.43 × 0.42		

P = 165.3 mm

Standoff 4.0 CD, 50.8-mm RHA blocks

Block No.	Entrance Hole (cm)	Exit Hole (cm)	Comments
1	0.79 × 0.96	0.60 × 0.83	
2	0.56 × 0.76		

P = 81.1 mm

Standoff 4.0 CD, 50.8-mm RHA blocks

Block No.	Entrance Hole (cm)	Exit Hole (cm)	Comments
1	0.66 × 1.0	0.97 × 1.02	
2	0.77 × 0.81		

P = 74.5 mm

Standoff 6.0 CD, 50.8-mm RHA blocks

Block No.	Entrance Hole (cm)	Exit Hole (cm)	Comments
1	0.95 × 0.87		Irregular, oblong hole

P = 28.8 mm

Standoff 6.0 CD, 50.8-mm RHA blocks

Block No.	Entrance Hole (cm)	Exit Hole (cm)	Comments
1	0.71 × 0.88	0.74 × 0.64	Irregular, oblong hole
2	0.53 × 0.76		

P = 74.6 mm

Standoff 6.0 CD, 50.8-mm RHA blocks

Block No.	Entrance Hole (cm)	Exit Hole (cm)	Comments
1	0.79 × 1.02		

P = 43.1 mm

Penetration Into 25.4-mm Blocks

Standoff 4.0 CD, 25.4 mm RHA blocks

Block No.	Entrance Hole (cm)	Exit Hole (cm)	Comments
1	0.8 × 0.72	0.82 × 0.45	slot
2	0.88 × 0.86	0.55 × 0.45	entrance plugged
3	0.45 × 0.495	1.42 × 1.80	large exit plug
4	1.78 × 1.77		entrance plugged large splash area

P = 76.2 mm + plug

Standoff 3.0 CD, 25.4 mm RHA blocks

Block No.	Entrance Hole (cm)	Exit Hole (cm)	Comments
1	0.87 × 0.71	0.68 × 0.73	
2	0.65 × 0.62	0.82 × 0.73	Cu splash
3	0.52 × 0.74	1.03 × 1.13	Cu splash; rear bulge
4	1.09 × 1.29		entrance indentation

P = 76.2 mm

Standoff 3.0 CD, 25.4 mm RHA blocks

Block No.	Entrance Hole (cm)	Exit Hole (cm)	Comments
1	0.775 × 0.81	0.57 × 0.6	
2	0.56 × 0.53	0.5 × 0.48	
3	0.48 × 0.49	0.48 × 0.42	
4	0.45 × 0.445	0.50 × 0.45	exit plugged
5	0.52 × 0.53	0.37 × 0.35	entire hole plugged
6	0.42 × 0.48	0.51 × 0.59	entire hole plugged
7	0.95 × 0.62		entire hole plugged

P = 152.4 mm + plug

Standoff 3.0 CD, 25.4 mm RHA blocks, 60° obliquity

Block No.	Entrance Hole (cm)	Exit Hole (cm)	Comments
1	1.07 × 1.01	0.625 × 0.58	
2	0.59 × 0.61	0.59 × 0.50	
3	0.71 × 0.61	0.65 × 0.76	hole plugged
4	0.47 × 0.44		hole plugged

P = 152.4 mm + plug (Line-of-sight penetration)

Standoff 3.0 CD, 25.4 mm RHA blocks, 60° obliquity

Block No.	Entrance Hole (cm)	Exit Hole (cm)	Comments
1	0.945 × 1.125	0.82 × 0.62	slot
2	0.52 × 0.74	0.78 × 0.67	
3	0.86 × 0.74		16.4 mm penetration (line-of-sight)

P = 118.1 mm (line-of-sight)

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13. ABSTRACT *(Maximum 200 words)*

A study was conducted to characterize and investigate the performance of shaped charge devices fabricated with powder metal liners. The investigation involved free-flight flash radiography characterization of the jet to obtain the penetrator characteristics and the penetration and hole size into rolled homogeneous armor (RHA) plate at several standoff distances.

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